To the Graduate Council:

I am submitting herewith a thesis written by Jeremy Tate Walters entitled "Effects of Risk on Optimal Nitrogen Fertilization Rates and Dates in Winter Wheat Production as Affected by Disease and Nitrogen Source." I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Economics.

Roland K. Roberts, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the council:

Vice Provost and Dean of Graduate Studies

# Effects of Risk on Optimal Nitrogen Fertilization Rates and Dates in Winter Wheat Production as Affected by Disease and Nitrogen Source

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Jeremy Tate Walters
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# DEDICATION

This thesis is dedicated to my son

Hunter Tate Walters

my wife

Michelle Walters

my parents

Gary and Diana Walters

and my brother

Adam Walters

who have always supported and encouraged

me in all I have done.

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The greatest appreciation of all goes to God, my wife and son, and my parents who have been my greatest supporters. God has given me the strength, courage, and a supporting family to make it through this program. My wife has always been there to support me and encourage me to do my best and my son makes life better then I ever thought possible. My parents have always given me the support and extra little push to accomplish whatever I do.

# ABSTRACT

Efficient nitrogen (N) fertilization practices increase the economic benefit of N in wheat (Triticum aestivum L.) production and the timing of N in wheat production is an important management decision. Although N fertilization increases wheat yields, it can also affect production risk measured by yield variability (risk). Yield and risk can also be affected by interactions among N source, N rate, N timing and disease severity. Because of production risk, some farmers may apply more N than can be efficiently utilized by the crop and if N fertilization is not timed for accelerated N uptake by the plant, optimal yields are not obtained. By adjusting application of N fertilizer to efficient levels and adjusting the application date of N fertilizer to optimize N uptake, farmers can achieve greater economic returns.

The first objective of this research was to evaluate the effects of N source, N rate, N timing and disease severity on expected yield and risk in wheat production and to evaluate the risk-and-return trade-offs among alternative N sources for farmers with different risk preferences. The second objective was to determine utility-maximizing N rates, N fertilization dates, yields, and net returns.

A Just-Pope econometric analysis isolates the impacts of changes in input use on both expected yield and risk. The model takes the form:

(1) $Y_t = f(X_t,\beta)+h(Z_t,\alpha)\varepsilon_t$,

where Y was wheat yield (bu/acre); X and Z were matrices of explanatory variables; t was a subscript for year; $\beta$ and $\alpha$ were parameter vectors; and $\varepsilon$ was a random error term

with a mean of zero. The production function, $f(X_t,\beta)$, relates $X_t$ to mean wheat yield. The variance function, $h(Z_t,\alpha)$, associates $Z_t$ to risk.

The estimated mean yield response function and the variance function for each N source were used to predict certainty equivalent. The certainty equivalent maximizing N fertilizer levels and dates for each N source were found for risk neutrality ($\lambda = 0$) and two levels of risk aversion ($\lambda = 0.01$ and $\lambda = 0.02$).

The estimated coefficients for N and $N^2$ were positive and negative, respectively, but the $N^2$ coefficients for Urea and UAN were not significantly different from zero. The coefficients for time and $time^2$ were positive and negative, respectively.

The coefficient for the N-Take-All interaction (NTA) for Urea was significant at the 10-percent level and the N-Glume-Blotch interaction (NG) for UAN was significant at the 1-percent level. Notwithstanding the significance of these coefficients in the regressions, the F-tests indicated that N did not affect risk for any N source when all N variables (N, NG, NTA) were considered jointly. No time coefficients had an affect on risk.

Each N source was evaluated under the assumption of risk neutrality ($\lambda = 0$) and two level of risk aversion ($\lambda = 0.01$ and $\lambda = 0.02$) for mean disease ratings. In this evaluation neither N nor time had an affect on risk. At mean values of the disease variables, AN was the utility maximizing N source regardless of the farmer's risk preferences.

AN was the utility maximizing N source, with an optimal N rate around 90 lb/acre and an optimal fertilization date of March 8 regardless of the individual's risk aversion level.

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## Introduction

Efficient nitrogen (N) fertilization practices increase the economic benefit of N in wheat (Triticum aestivum L.) production (Fiez, 1995) and the timing of N in wheat production is an important management decision (Boman, 1995). Although N fertilization increases wheat yields, it can also affect production risk (Just and Pope, 1979) measured by yield variability (risk). Yield and risk can also be affected by interactions among N source, N rate, N timing and disease severity (Alcoz, 1993; Colbach, 1997; Eilrich, 1973; Wiese, 1987; MacNish, 1980; Brennan, 1992a, Brennan, 1992b). Because of production risk, some farmers may apply more N than can be efficiently utilized by the crop (Peters, 1999) and if N fertilization is not timed for accelerated N uptake by the plant, optimal yields are not obtained. By adjusting application of N fertilizer to efficient levels and adjusting the application date of N fertilizer to optimize N uptake, farmers can achieve greater economic returns.

N fertilization has been found to be both risk increasing (Larson, 2001; Roumasset, 1989) and risk reducing (Larson, 1998; Antle and Crissman, 1990; Lambert, 1990). The potential impact of N fertilizer on yield variability is influenced by the crop production system (e.g., dry land production versus irrigated production) and other management factors in addition to N (Larson, 2001). Although, these studies evaluated N and risk, they did not evaluate the risk effects of alternative N sources in the presence of disease.

Previous research found that applying N at Feekes' Growth Stages 4 to 6 significantly increased yields (Alcoz, 1993). However, Boman (1995) found N can be delayed until later in the season without significantly affecting yields. Disease control is necessary since disease stress may reduce N uptake (Dilz, 1982). Intensive management systems need to be flexible so that N timing and fungicide applications are based on the characteristics of each wheat crop and environment (Roth, 1987). These studies evaluated N timing and disease severity at different growth stages and the effects on yield; however, they did not evaluate the risk effects of N timing in the presence of disease.

Glume-Blotch (*Stagonospora nodorum*) is a late-season head infection (Ditsch, 1991). N fertilization of wheat can interact with Glume-Blotch to limit wheat yields (Boquet, 1987). However, N availability was an important determinant of yield because the wheat plant requires high amounts of N during grain fill (Beuerlein, 1991). The lush vegetative growth that accompanies high N fertilization reduces air movement through the canopy, producing an environment more suited for Glume-Blotch development (Ditsch, 1991; Wiese, 1987). Without fungicide application in the presence of Glume-Blotch, higher N levels significantly reduced wheat yield (Kelley, 1993; Howard, 1994; Cox, 1989; Roth, 1987; Ditsch, 1991). Roth (1987) showed that Glume-Blotch severity was lowest at a zero N rate and increased for rates above 70 lb N/acre; however, Orth (1994) found that increased N significantly decreased susceptibility to Glume-Blotch infection. Although these studies found that N rate and timing affect Glume-Blotch severity and yield, they did not evaluate the affects of N rate, N timing, and Glume-Blotch severity on risk. In addition, no other studies were found evaluating the affects of Glume-Blotch severity and risk.

Take-All (*Gaeumannomyces graminis* var. *tritici*) infections in autumn or early spring are most likely to affect wheat yield (Wiese, 1987), while later infections are less likely to affect yield. The severity of this root disease in wheat production was influenced by the N source, with more severe root damage in plots fertilized with nitrate ($NO_3^-$) compared with ammonium ($NH_4^+$) forms of N (Colbach, 1997; Wiese, 1987; MacNish, 1980; Brennan, 1992a; Brennan, 1992b). Ammonium fertilizers may reduce Take-All severity because of decreased rhizosphere pH that promotes more vigorous root growth, allowing roots to escape severe disease damage (Brennan, 1989). Brennan (1992a) found that 100 lb N/acre significantly reduced Take-All severity when ammonium forms were applied to wheat. However, where Take-All is at high levels, ammonium forms of N are ineffective in reducing Take-All severity (MacNish, 1980). These studies showed that N source and N rate affect Take-All severity and yield. However, they did not evaluate the effects of N source, N rate, N timing and Take-All severity on risk.

## Objectives

A comprehensive evaluation of the interactions among N sources, N rates, N timing, disease pressure of Glume-Blotch and Take-All and their affects on expected yield and risk has not been found. The first objective of this research was to evaluate the effects of N source, N rate, N timing and disease severity on expected yield and risk in wheat production and to evaluate the risk-and-return trade-offs among alternative N sources for farmers with different risk preferences. The second objective was to determine utility-maximizing N rates, yields, and net returns.

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## Part 2: Effects of Risk on Optimal Nitrogen Fertilization Rates in Winter Wheat Production as Affected by Disease and Nitrogen Source

## Introduction

Efficient N fertilization practices increase the economic benefit of N in wheat production (Fiez, 1995). Although N fertilization increases wheat yields, it can also affect production risk (Just and Pope, 1979) measured by yield variability (risk). Yield and risk can also be affected by interactions among N source, N rate and disease severity (Colbach, 1997; Wiese, 1987; MacNish, 1980; Brennan, 1992a, Brennan, 1992b). Because of production risk, some farmers may apply more N than can be efficiently utilized by the crop (Peters, 1999). By adjusting application of N fertilizer to efficient levels, farmers can achieve greater economic returns.

N fertilization has been found to be both risk increasing (Larson, 2001; Roumasset, 1989; Just and Pope, 1979) and risk reducing (Larson, 1998; Antle and Crissman, 1990; Lambert, 1990). The potential impact of N fertilizer on risk is influenced by the crop production system (e.g., dry land production versus irrigated production) and other management factors in addition to N (Larson, 2001). Although, these studies evaluated N and risk, they did not evaluate the risk effects of alternative N sources in the presence of disease.

High N fertilization rates of Soft Red Winter Wheat (wheat) can interact with Glume-Blotch to limit yield (Boquet, 1987). The lush vegetative growth that accompanies high N fertilization reduces air movement through the canopy, producing an environment more suited for Glume-Blotch development (Ditsch, 1991; Wiese, 1987). Without fungicide application in the presence of Glume-Blotch, higher N levels significantly reduced wheat yield (Kelley, 1993; Howard, 1994; Cox, 1989; Roth, 1987; Ditsch, 1991). Roth (1987) showed that Glume-Blotch severity was lowest at a zero N rate and increased for rates above 70 lb N/acre; however, Orth (1994) found that higher levels of N significantly decreased susceptibility to Glume-Blotch infection. Although these studies found that N rate affects Glume-Blotch severity and yield, they did not evaluate the affects of N rate and Glume-Blotch severity on risk. In addition, no other studies were found evaluating the affects of Glume-Blotch severity and risk.

The severity of the root disease, Take-All, in wheat production was influenced by the N source, with more severe root damage in plots fertilized with nitrate ($NO_3^-$) compared with ammonium ($NH_4^+$) forms of N (Colbach, 1997; Wiese, 1987; MacNish, 1980; Brennan, 1992a; Brennan, 1992b). Ammonium fertilizers may reduce Take-All severity because of decreased rhizosphere pH that promotes more vigorous root growth, allowing roots to escape severe disease damage (Brennan, 1989). Brennan (1992a) found that 100 lb N/acre significantly reduced Take-All severity when ammonium forms were applied to wheat. However, where Take-All is at high levels, ammonium forms of N are ineffective in reducing Take-All severity (MacNish, 1980). These studies showed that N source and N rate affect Take-All severity and yield. However, they did not evaluate the affects of N rate, N source and Take-All severity on risk.

A comprehensive evaluation of the interactions among N rates, N sources, disease pressure of Glume-Blotch and Take-All and their affects on expected yield and risk has not been found. The first objective of this research was to evaluate the affects of N source, N rate, and disease severity on expected yield and risk in wheat production and to evaluate the risk-and-return trade-offs among alternative N sources for farmers with different risk preferences. The second objective was to determine utility-maximizing N rates, yields, and net returns.

## Analytical Framework

Farmers can use measures of expected yield and risk to make decisions in wheat production (Barry, 1984). A Just-Pope (1978 and 1979) econometric analysis was one method for evaluating risk. It isolates the impacts of changes in input use on both expected yield and risk. This method has been used to evaluate the risk effects of genetic improvement of wheat yields during the green revolution (Traxler, 1995); winter cover crop, tillage, and N fertilization systems in cotton production (Larson et al., 2001); the relationship between genetic resources and diversity variables in wheat production (Smale, 1998); and N as a non-point pollution problem with alternative policies and farmer response to those policies (Lambert, 1990).

The Just-Pope econometric model takes the form:

(1) $$Y_t = f(X_t,\beta)+h(Z_t,\alpha)\varepsilon_t,$$

where Y was wheat yield (bu/acre); X and Z were matrices of explanatory variables; t was a subscript for year; $\beta$ and $\alpha$ were parameter vectors; and $\varepsilon$ was a random error term with a mean of zero. The production function, $f(X_t,\beta)$, relates $X_t$ to mean wheat yield. The variance function, $h(Z_t,\alpha)$, associates $Z_t$ to risk.

## Data and Empirical Methods

### *Yield Data*

Wheat yields for 1998 through 2000 were obtained from a wheat fertilization experiment at the West Tennessee Experiment Station, Jackson, Tennessee (Howard et al., 2002). Planting dates were 22 Oct. 1997, 9 Oct. 1998 and 15 Oct. 1999. The experimental design was a split plot with treatments replicated five times. Main plots were treated with 0, 30, 60, 90, 120 and 150 lb N/acre in the spring. Treatments included three N sources: Ammonium Nitrate ($NH_4NO_3$) (AN), Urea ($NH_2$-CO-$NH_2$), and Urea-Ammonium Nitrate ($NH_2$-CO-$NH_2$+$NH_4NO_3$+$H_2O$) (UAN). N rates were applied at Feekes' growth stage (GS) 6 when the first node of the stem was visible (Large, 1954) (Figure 1, Part 3). Individual plots were 40 feet long and 12 feet wide. Glume-Blotch affected the 1998 crop and Take-All affected the 2000 crop. Both diseases occurred naturally. In 1998, Propiconazole (1-[[2-(2,4-dichlorophenyl)-4-propyl- 1, 3-dioxolan-2-yl] methyl]-1h-1,2,4-trizole) was applied at 0.030624 gallons per acre at GS 9 with a second application at GS 10 before heading to control Glume-Blotch severity. In 1999 and 2000, a single application of Quadris (azoxystrobin: methyl (E)-2(2-{6-(2-cyanophenoxyl)pyrimidin-4-yloxylphenyl}-3-methoxyacrylate)) was applied at 0.0616704 gallons per acre at GS 9 to control disease severity. Propiconazole and Quadris are both foliar fungicides used to control Glume-Blotch severity (Bailey, 2002). No chemicals were applied to control Take-All because no effective chemical control exists to limit Take-All severity (Colbach, 1997). Disease ratings were recorded each year at GS 10.1 when the sheath of the last leaf was completely grown out. Disease ratings were recorded on a scale of zero to ten, with ten being the most severe disease rating and zero being no disease present. Plots were harvested mid-June.

*Empirical Model*

A Just-Pope model was specified to evaluate the risk effects on wheat production of three N sources and two diseases at six N fertilization rates. The mean yield production function, $f(X_t,\beta)$, for each N source was estimated as a quadratic function of the management variable N;

$$(2) \qquad Y_t = \beta_0+\beta_1 N_t+\beta_2 N_t^2+e_t,$$

where Y was wheat yield (bu/acre); N was the N rate (lb/acre); t was a subscript indicating year; $\beta_0$, $\beta_1$ and $\beta_2$ were parameters to be estimated; and e was a random error term with a mean of zero. N was hypothesized to exhibit diminishing marginal productivity ($\beta_1 > 0$, $\beta_2 < 0$) (Frank, 1990; Larson, 2001 and Llewelyn, 1997).

The variance of yield function, $h(Z_t,\alpha)\varepsilon_t$, was estimated using the residuals obtained from the estimated mean yield production function. Because Glume-Blotch and Take-All severity affect wheat yield differently at different N rates (Boquet, 1987; Colbach, 1997), variance of yield was specified as a function of N rate, Glume-Blotch rating, Take-All rating, two dummy variable for disease presence, an interaction between N rate and Glume-Blotch rating, and an interaction between N rate and Take-All rating. The Just-Pope approach enables direct statistical testing of hypotheses about how N rate, Glume-Blotch severity, and Take-All severity interact to influence risk in wheat production for alternative N sources at different N rates. The variance of yield function for each N source was specified as:

$$(3)\ \ln\hat{e}_t^2 = \alpha_0+\alpha_1N_t+\alpha_2G_t+\alpha_3DG_t+\alpha_4NG_t+\alpha_5TA_t+\alpha_6DTA_t+\alpha_7NTA_t+u_t,$$

where $\ln\hat{e}_t^2$ was the natural log of the squared residuals from the estimation of equation 2; N was the N rate (lb/acre); G was Glume-Blotch rating, with 10 being the most severe disease rating and zero being when no disease was present; DG was a dummy variable equal to one when Glume-Blotch was present and zero otherwise; NG was an interaction term between N rate and Glume-Blotch rating; TA was the Take-All rating, with 10 being the most severe disease rating and zero being when no disease was present; DTA was a dummy variable equal to one when the disease was present and zero otherwise; NTA was an interaction term between N rate and Take-All rating; t was a subscript indicating year; $\alpha_i$ ($i = 0,1,\ldots, 7$) were parameters to be estimated; and u was a random error term with a mean of zero.

Efficiency gains in parameter estimates are possible with weighted least squares (WLS) when multiplicative heteroscedasticity is found. Multiplicative heteroscedasticity in the mean yield equations (2) was tested using the model F-statistic from the individual N-source variance equations (Judge et al.,1982). If the F-statistic was significant, the null hypothesis of homoscedasticity was rejected and multiplicative heteroscedasticity was assumed. Predicted values from equation 3 were used as weights for producing WLS estimates for the mean yield equation (equation 2) for each N source.

Net returns were calculated using an average wheat price of $3.43/bu for 1991-2000 (Tennessee Department of Agricultural, 2001). Wheat prices were inflated to 2002 dollars by the Gross Domestic Product Implicit Price Deflator (U.S. Department of Commerce: Bureau of Economic Analysis, 2002) before averaging. N fertilizer prices were obtained from the Tennessee Farmers Cooperative. Tennessee average retail prices paid by farmers for 2002 were: AN = \$0.26/lb; Urea = \$0.21/lb; and UAN = \$0.23/lb (Personal Communication, John Duke, Tennessee Farmers Cooperative, June 17, 2002). All prices were for pure N. Other production costs were assumed to remain unchanged among alternatives.

The estimated mean yield response function and the variance function for each N source were used to predict certainty equivalent optimizing levels of applied N, yield, cost, and net return above N cost. Certainty equivalent profit per acre was approximated as (Robison and Barry, 1987):

(4) $CE = E(NR) - \lambda/2 \, Var(NR)$,

where E(NR) was expected net return, $\lambda$ was the value of the Pratt-Arrow absolute risk aversion coefficient, and Var(NR) was the variance of net return. E(NR) was calculated using the following formula:

(5) $E(NR) = (Y*WP)-(N*NP)$,

where Y was the wheat yield (bu/acre); WP was the average wheat price per bushel from 1991-2000; N was the N rate (lb/acre); and NP was the N price per pound of pure N. Var(NR) was calculated using the following formula (Bohrnstedt and Goldberger, 1969):

(6) $Var(NR) = (Y^2)*WP_{var}+WP^2(Y_{std})+WP_{var}(Y_{std})$,

where Y was wheat yield (bu/acre); WP was the average wheat price per bushel from 1991-2000; $WP_{var}$ was the wheat price variance from 1991-2000 of $0.61/bu; $Y_{std}$ was the standard deviation of wheat yield obtained from equation 3.

The certainty equivalent maximizing N fertilizer level for each N source was found by solving:

(7) $$\max CE = E(NR) - \lambda/2\ Var(NR),$$

$$s.t.\ \ 0 \leq N \leq 150 \text{ lb N/acre}.$$

Equation 7 was solved for risk neutrality ($\lambda = 0$) and two levels of risk aversion ($\lambda = 0.01$ and $\lambda = 0.02$) consistent with the range of risk aversion evaluated by Lambert (1990) and Larson (2001).

Farmers' willingness to pay was the maximum dollar amount they would pay for the knowledge that one N source was more profitable than another N source for each risk aversion level and be just as well off. Dollar amounts lower then the willingness to pay would be considered profit by farmers and be an incentive to switch N sources. Willingness to pay was calculated by determining the difference between the certainty equivalents of the N sources for risk neutrality and the two levels of risk aversion.

## Results and Discussion

### *Mean Yields*

The mean yield response functions were estimated with WLS (Table 1) after the F-statistics from the variance of yield equations indicated multiplicative heteroscedasticity. The WLS coefficients for N and $N^2$ had the hypothesized signs, but the $N^2$ coefficients for Urea and UAN were not significantly different from zero. The Urea and UAN functions were close to being linear (Figure 1), and the estimated maximum yield for the Urea function was outside the range of the data (181lb N/acre). The low $R^2$ coefficients suggest that a considerable amount of variation in wheat yield was not explained by the management variable N. Error sums of squares from the OLS regressions for the mean yield functions (equation 2) indicate that AN produced the least variable wheat yields followed by Urea and UAN, all other factors being equal (Table 1). Comparisons of the error sums of squares indicated that AN was significantly different from Urea and UAN in explaining yield variance (Table 2). However, yield variance for Urea and UAN were not significantly different from each other.

### *Variance of Yields*

The variance of yield equations are presented in Table 3 and joint F-tests for the N and disease coefficients are presented in Table 4. The coefficient for the N-Take-All interaction (NTA) for Urea was significant at the 10-percent level and positively affected risk. The N-Glume-Blotch interaction (NG) for UAN was significant at the 1-percent level and negatively affected risk. Notwithstanding the significance of these coefficients in the regressions, the F-tests (Table 4) indicated that N did not significantly affect risk for any N source when all N variables (N, NG, NTA) were considered jointly.

The dummy variable coefficient for Glume-Blotch (DG) was significant at the 1-percent level and negatively affected risk for all N sources. The Glume-Blotch rating coefficients (G, NG) were significant at the 1-percent level for UAN; G positively affected risk and NG negatively affected risk. The joint F-tests (Table 4) indicated that in the presence of Glume-Blotch, UAN significantly reduced risk (Table 5) from no disease present to the mean Glume-Blotch rating with other variables held constant at their means. Glume-Blotch reduces risk possibly because it affects dense canopy wheat when yields are typically highest (Ditsch, 1991; Wiese, 1987). Thus, Glume-Blotch may reduce yields most in high-yielding areas of the field and in higher than average yield years compared with lower productivity years.

The Take-All rating coefficient (TA) and the dummy variable coefficient (DTA) were significant at the 5-percent level for all N sources. The Take-All rating positively affected risk and DTA negatively affected risk. The Take-All-N interaction coefficient (NTA) was significant at the 10-percent level for Urea and positively affected risk. The joint F-tests (Table 4) indicated that, in the presence of Take-All, UAN significantly reduced risk (Table 5) from no disease present to the mean Take-All rating, with other variables at their means. Take-All reduces risk possibly because yields are reduced most in high-yielding areas of the field and in higher than average yield years when nitrate forms of N are applied, thus tending to equalize yields across the field and across years.

Pair-wise F-tests indicated that N does not affect risk differently among N sources (Table 6). Glume-Blotch had similar risk affects on wheat production when AN and

Urea were applied, but when UAN was applied risk was affected differently; UAN was significant in reducing risk, whereas AN and Urea were not significant in affecting risk when Take-All was present. Take-All had similar risk affects on wheat production when AN and Urea were applied, but when UAN was applied risk was affected differently. UAN was significant in reducing risk (Tables 4 and 5), whereas AN and Urea did not significantly affect risk in the presence of Take-All (Table 4). Similar to the Glume-Blotch and Take-All effects, the joint influence of all variables on risk was different for UAN then for AN and Urea.

*Risk-Return Trade-offs*

Optimal N rates, wheat yields, wheat yield standard deviations, net return means, and certainty equivalents for each N source under the assumptions of risk neutrality ($\lambda$ = 0) and two level of risk aversion ($\lambda$ = 0.01 and $\lambda$ = 0.02) for mean disease ratings are presented in Table 7. Optimal N rates were 92 (90) ((87)), 147 (142) ((136)) and 117 (114) ((110)) lb/acre for risk neutrality and the two levels of risk aversion for AN, Urea and UAN. Optimal wheat yields were 69, 71 and 64 bu/acre for AN, Urea, and UAN. Optimal net returns were \$214, \$212 and \$196 for AN, Urea and UAN, respectively. Certainty equivalents were \$214.27 (\$198.92) ((\$183.92)), \$211.77 (\$195.87) ((\$180.15)) and \$195.76 (\$182.63) ((\$169.58)) for risk neutrality and the two levels of risk aversion for AN, Urea and UAN. Farmers willingness to pay was \$2.50 (\$3.05) ((\$3.52)), \$18.51 (\$16.29) ((\$14.09)) and \$16.01 (\$13.24) ((\$10.57)) per acre for risk neutrality and the two levels of risk aversion for AN vs. Urea, AN vs. UAN and Urea vs. UAN.

Certainty equivalents can be used to rank N sources for individuals with different levels of risk aversion. AN had the highest net returns and the highest certainty equivalents at all levels of risk aversion evaluated. AN was the utility maximizing N source for all levels of risk aversion. Results indicate that farmers will maximize utility and net returns if they apply AN at rates around 90 lb N/acre.

## Summary

This study evaluated risk efficiency of alternative N sources and six different application rates in wheat production in the presence of two diseases (Glume-Blotch and Take-All). A Just-Pope econometric model was developed to analyze the risk effects of alternative N sources and to evaluate risk and return tradeoffs among these N sources.

The results indicated that N had no affect on risk; the presence and severity of disease had an influence on risk; and AN was the optimal N source. In the presence of Glume-Blotch and Take-All, UAN significantly reduced risk at mean N rates and disease ratings, but risk was not reduced sufficiently for UAN to replace AN as the utility maximizing N source. The risk-return trade-offs suggested that N had no effect on utility maximizing N source at the different risk aversion levels. This information could be used to recommend that farmers apply AN at an rate of around 90 lb N/acre regardless of their risk aversion.

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Appendix

**Table 1.** Estimated Weighted Least Squares Wheat Yield Response Functions for Alternative Nitrogen Sources, Nitrogen Rate Equations.

| | Nitrogen Sources | | |
|---|---|---|---|
| **Variables**[a] | **AN** | **Urea** | **UAN** |
| **Intercept** | 41.88*** | 42.059*** | 42.10*** |
| | (4.25)[b] | (5.21) | (5.21) |
| **N** | 0.52*** | 0.33** | 0.32* |
| | (0.13) | (0.16) | (0.17) |
| **$N^2$** | -0.0024** | -0.00091 | -0.0011 |
| | (0.00091) | (0.0011) | (0.0011) |
| **$R^2$** | 0.23 | 0.18 | 0.12 |
| **Error Sums of Squares**[c] | 23,927 | 32,328 | 34,162 |
| **n** | 90 | 89 | 90 |

[a] Wheat yield (bu/acre) is the dependent variable and N is pure nitrogen applied (lb/acre).
[b] Numbers in parenthesis are standard errors.
***, **, and * significantly different from zero at the 1, 5, or 10-percent levels, respectively.
[c] From OLS estimates.

**Table 2.** Comparisons of the Error Sums of Squares from the OLS Mean Yield Response Functions.

| Comparisons | F-statistic |
|---|---|
| AN vs Urea[a] | 1.38* |
| AN vs UAN[b] | 1.43** |
| Urea vs UAN[c] | 1.04 |

[a] Degrees of freedom were 87 in the numerator and 86 in the denominator.
[b] Degrees of freedom were 87 in the numerator and 87 in the denominator.
[c] Degrees of freedom were 86 in the numerator and 87 in the denominator.
** and * significantly different from zero at the 5 or 10-percent level, respectively.

**Table 3.** Estimated Ordinary Least Squares Wheat Variance Functions for Alternative Nitrogen Sources, Nitrogen Rate Equations.

| | Nitrogen Sources | | |
|---|---|---|---|
| **Variables**[a] | **AN** | **Urea** | **UAN** |
| **Intercept** | 6.050*** | 6.18*** | 6.14*** |
| | (0.43)[b] | (0.47) | (0.46) |
| **N** | -0.0017 | 0.00017 | 0.00083 |
| | (0.0044) | (0.0049) | (0.0049) |
| **G** | -0.020 | 0.17 | 1.11*** |
| | (0.24) | (0.30) | (0.30) |
| **DG** | -3.26*** | -3.75*** | -6.37*** |
| | (1.084) | (1.18) | (1.088) |
| **NG** | 0.00070 | -0.0013 | -0.0064*** |
| | (0.0013) | (0.0017) | (0.0017) |
| **TA** | 0.30** | 0.37** | 0.41*** |
| | (0.14) | (0.15) | (0.15) |
| **DTA** | -2.40*** | -3.18*** | -3.29*** |
| | (0.60) | (0.66) | (0.66) |
| **NTA** | 0.0034 | 0.0035* | 0.0022 |
| | (0.020) | (0.0018) | (0.0015) |
| **F-statistic** | 11.41*** | 13.08*** | 18.63*** |
| **$R^2$** | 0.49 | 0.53 | 0.61 |
| **n** | 90 | 89 | 90 |

[a] Wheat yield (bu/acre) is the dependent variable; N = pure nitrogen applied (lb/acre); G = Glume-Blotch rating from 0 to 10, 0 meaning no Glume-Blotch present and 10 meaning most severe cases; DG is a dummy variable equal to one when Glume-Blotch was present and zero otherwise; NG is an interaction term between N rate and Glume-Blotch rating; TA = Take-All rating from 0 to 10, 0 meaning no Take-All present and 10 being the most severe cases. DTA is a dummy variable equal to one when Take-All was present and zero otherwise; NTA is an interaction term between N rate and Take-All rating.

[b] Numbers in parenthesis are standard errors.

***, **, and * significantly different from zero at the 1, 5 or 10-percent levels, respectively.

**Table 4.** Joint F-tests for the Nitrogen Rate, Glume-Blotch, and Take-All Coefficients within the Variance Equations for each Nitrogen Source, Nitrogen Rate Equations.

| Comparisons | F-statistic |
|---|---|
| **Nitrogen**[a] | |
| AN | 0.78 |
| Urea | 1.42 |
| UAN | 0.87 |
| | |
| **Glume-Blotch**[b] | |
| AN | 0.23 |
| Urea | 0.10 |
| UAN | 34.47*** |
| **Take-All**[c] | |
| AN | 2.13 |
| Urea | 0.03 |
| UAN | 21.42*** |

[a] The F-statistic tests the null hypothesis that the coefficients for N, NG, and NTA are jointly equal to zero for a given N source.

[b] The F-statistic tests the null hypothesis that the coefficients for G, DG, and NG are jointly equal to zero for a given N source.

[c] The F-statistic test the null hypothesis that the coefficients for TA, DTA, and NTA are jointly equal to zero for a given N source.

*** significantly different from zero at the 1-percent levels.

**Table 5.** Estimated Effects of Glume-Blotch and Take-All on Risk for UAN.

| | Glume-Blotch | | Take-All | |
|---|---|---|---|---|
| **Variable** | No disease[a] | Mean disease[b] | No disease[c] | Mean disease[d] |
| **N** | 90 | 90 | 90 | 90 |
| **G** | 0 | 6.38 | 2.13 | 2.13 |
| **DG** | 0 | 1 | 0.33 | 0.33 |
| **NG** | 0 | 574.2 | 191.4 | 191.4 |
| **TA** | 1.16 | 1.16 | 0 | 3.47 |
| **DTA** | 0.33 | 0.33 | 0 | 1 |
| **NTA** | 104.1 | 104.1 | 0 | 312.3 |
| **Wheat Yield Std. Dev. (bu/acre)** | 18.5 | 4.2 | 13.8 | 7.6 |

[a] Variables other than G, DG, and NG are held constant at their three-year means.

[b] Glume-Blotch variables G, DG, and NG are at their 1998 means; other variables are held constant at their three-year means.

[c] Variables other than TA, DTA, and NTA are held constant at their three-year means.

[d] Take-All variables TA, DTA, and NTA are at their 2000 means; other variables are held constant at their three-year means.

**Table 6.** Pair-Wise F-tests for the Nitrogen Rate, Glume-Blotch and Take-All Coefficients between Nitrogen Sources, Nitrogen Rate Equations.

| Comparisons | F-statistic |
|---|---|
| **Nitrogen**[a] | |
| AN-Urea | 0.00 |
| AN-UAN | 1.00 |
| Urea-UAN | 1.48 |
| **Glume-Blotch**[b] | |
| AN-Urea | 0.03 |
| AN-UAN | 7.72*** |
| Urea-UAN | 7.46*** |
| **Take-All**[c] | |
| AN-Urea | 1.49 |
| AN-UAN | 8.83*** |
| Urea-UAN | 4.58*** |
| **Equation**[d] | |
| AN-Urea | 0.54 |
| AN-UAN | 13.49*** |
| Urea-UAN | 10.28*** |

[a] The F-statistic test the null hypothesis that the coefficient for N, NG, and NTA are equal between N sources.

[b] The F-statistic test the null hypothesis that the coefficient for G, DG, and NG are equal between N sources.

[c] The F-statistic test the null hypothesis that the coefficient for TA, DTA, and NTA are equal between N sources.

[d] The F-statistic tests the null hypothesis that the yield variance equations are equal between N sources.

*** significantly different from zero at the 1 percent levels.

**Table 7.** Risk and Return Comparisons for Nitrogen Sources at Three Levels of Risk Aversion, Nitrogen Rate Equations.

| Nitrogen Sources[a] | Coefficient of Absolute Risk Aversion | | |
|---|---|---|---|
| | λ=0.00 | λ=0.01 | λ=0.02 |
| ***Ammonium Nitrate (AN)*** | | | |
| Nitrogen Fertilizer (lb/acre) | 92 | 90 | 87 |
| Wheat Yield (bu/acre) | 69 | 69 | 69 |
| Wheat Yield Std. Dev. (bu/acre) | 11 | 11 | 11 |
| Net Return Mean ($/acre) | $214.27 | $214.22 | $214.04 |
| Certainty Equivalent | $214.27 | $198.92 | $183.67 |
| ***Urea*** | | | |
| Nitrogen Fertilizer (lb/acre) | 147 | 142 | 136 |
| Wheat Yield (bu/acre) | 71 | 70 | 70 |
| Wheat Yield Std. Dev. (bu/acre) | 12 | 12 | 11 |
| Net Return Mean ($/acre) | $211.77 | $211.69 | $211.36 |
| Certainty Equivalent | $211.77 | $195.87 | $180.15 |
| ***Urea-Ammonium Nitrate (UAN)*** | | | |
| Nitrogen Fertilizer (lb/acre) | 117 | 114 | 110 |
| Wheat Yield (bu/acre) | 64 | 64 | 64 |
| Wheat Yield Std. Dev. (bu/acre) | 10 | 10 | 10 |
| Net Return Mean ($/acre) | $195.76 | $195.72 | $195.57 |
| Certainty Equivalent | $195.76 | $182.63 | $169.58 |

[a] Disease variables are held constant at their three-year means.

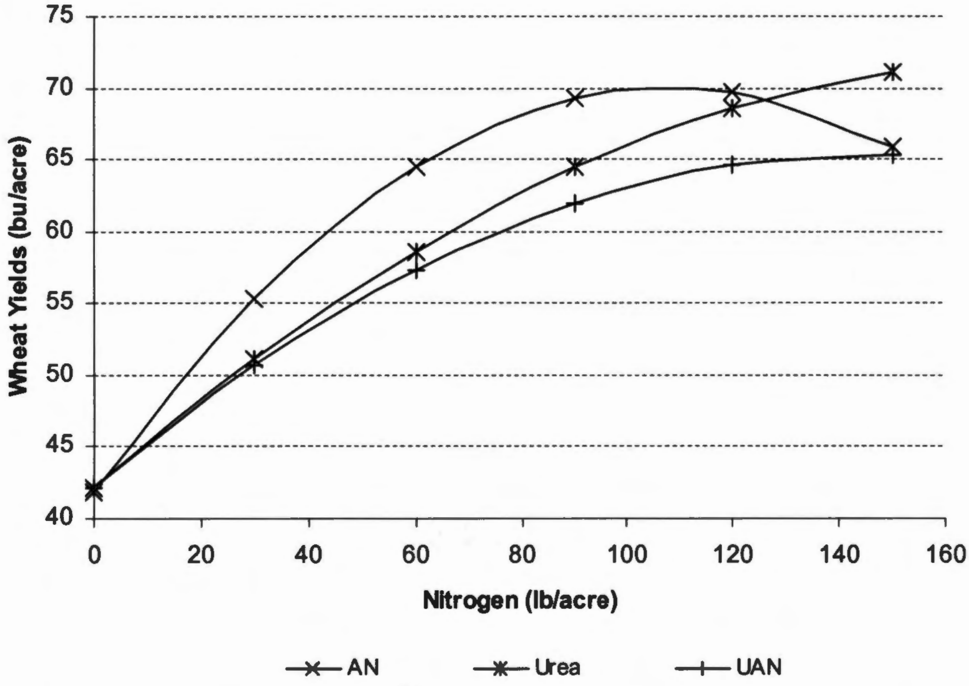


**Figure 1**. Nitrogen Fertilizer Rate Weighted Least Squares Yield Response Functions.

## Part 3: Effects of Risk on Optimal Nitrogen Fertilization Dates in Winter Wheat Production as Affected by Disease and Nitrogen Source

## Introduction

Timing of N fertilization in wheat production is an important management decision (Boman, 1995). N fertilization increases wheat yields, and can affect production risk (Just and Pope, 1979) measured by yield variability (risk). Yield and risk can also be affected by interactions among N timing, N source and disease severity (Alcoz, 1993; Eilrich, 1973). If N fertilization is not timed for accelerated N uptake by the plant, optimal yields are not obtained. By adjusting the application date of N fertilizer to optimize N uptake, farmers can achieve greater economic returns.

Previous research found that applying N at Feekes' Growth Stages 4 to 6 (Figure 1) significantly increased yields (Alcoz, 1993). However, Boman (1995) found N can be delayed until later in the season without significantly affecting yields. Disease control is necessary since disease stress may reduce N uptake (Dilz, 1982). Intensive management systems need to be flexible so that N timing and fungicide applications are based on the characteristics of each wheat crop and environment (Roth, 1987). These studies evaluated N timing and disease severity at different growth stages and the effects on yield; however, they did not evaluate the risk effects on yield of N timing in the presence of disease.

Glume-Blotch is a late-season head infection (Ditsch, 1991). N fertilization of wheat can interact with Glume-Blotch to limit wheat yields (Boquet, 1987). However, N availability was an important determinant of yield because the wheat plant requires high amounts of N during grain fill (Beuerlein, 1991). The lush vegetative growth that accompanies high N fertilization reduces air movement through the canopy, producing an environment more suited for Glume-Blotch development (Ditsch, 1991; Wiese, 1987).

Without fungicide application in the presence of Glume-Blotch, higher N levels significantly reduced wheat yield (Kelley, 1993; Howard, 1994; Cox, 1989; Roth, 1987; Ditsch, 1991). Although these studies found that N timing affects Glume-Blotch severity and yield differently, they did not evaluate the risk effects of N timing and Glume-Blotch severity. In addition, no other studies were found evaluating the effects of Glume-Blotch severity and risk on the N timing decision.

Take-All infections in autumn or early spring are most likely to affect wheat yield (Wiese, 1987), while later infections are less likely to affect yield. The severity of this root disease in wheat production was influenced by the N source, with more severe root damage in plots fertilized with nitrate ($NO_3^-$) compared with ammonium ($NH_4^+$) forms of N (Colbach, 1997; Wiese, 1987; MacNish, 1980; Brennan, 1992a; Brennan, 1992b). Ammonium fertilizers may reduce Take-All severity because of a decrease in rhizosphere pH that promotes more vigorous root growth, allowing roots to escape severe disease damage (Brennan, 1989). However, where Take-All is at high levels, ammonium forms of N are ineffective in reducing Take-All severity (MacNish, 1980). These studies showed that N source and N rate affect Take-All severity and yield. However, they did not evaluate the risk effects of N timing, N source and Take-All severity.

A comprehensive evaluation of the interactions among N timing, N sources, disease pressure of Glume-Blotch and Take-All, and their affects on expected yield and risk has not been found. The first objective was to evaluate the affects of N source, N timing, and disease severity on expected yield and risk in winter wheat production and to evaluate the risk-and-return trade-offs between N sources for farmers with different risk preferences. The second objective was to determine utility-maximizing fertilization dates, yields, and net returns.

## Analytical Framework

Farmers can use measures of expected yield and risk to make decisions in wheat production (Barry, 1984). A Just-Pope (1978 and 1979) econometric analysis was one method for evaluating risk. It isolates the impacts of changes in input use on both expected yield and risk. This method has been used to evaluate the risk effects of genetic improvement of wheat yields during the green revolution (Traxler, 1995); winter cover crop, tillage, and N fertilization systems in cotton production (Larson et al., 2001); the relationship between genetic resources and diversity variables in wheat production (Smale, 1998); and N as a non-point pollution problem with alternative policies and farmer response to those policies (Lambert, 1990).

The Just-Pope econometric model takes the form:

$$(1)\quad Y_t = f(X_t,\beta)+h(Z_t,\alpha)\varepsilon_t,$$

where Y was wheat yield; X and Z were matrices of explanatory variables; t was a subscript for year; β and α were parameter vectors; and ε was a random error term with a mean of zero. The production function, $f(X_t,\beta)$, relates $X_t$ to mean wheat yield. The variance function, $h(Z_t,\alpha)$, associates $Z_t$ to risk.

## Data and Empirical Methods

*Yield Data*

Wheat yields for 1998 through 2000 were obtained from a wheat fertilization experiment at the West Tennessee Experiment Station, Jackson, Tennessee (Howard et al., 2002). Planting dates were 22 Oct. 1997, 9 Oct. 1998 and 15 Oct. 1999. The experimental design was a split plot with treatments replicated five times. Main plot treatments were fertilized on 15 February, 1 March, 15 March, 1 April, and 15 April. These dates corresponded to Feekes' Growth Stages of 5, 6, 8, 9, and 10 (Large, 1952) (Figure 1). The N sources and fertilization rate were Ammonium Nitrate ($NH_4NO_3$) (AN) and Urea-Ammonium Nitrate ($NH_2$-CO-$NH_2$+$NH_4NO_3$+$H_2O$) (UAN), both applied at 90 lb N/acre. Individual plots were 40 feet long and 12 feet wide. Glume-Blotch affected the 1998 crop and Take-All affected the 2000 crop. Both diseases occurred naturally. In 1998, Propiconazole (1-[[2-(2,4-dichlorophenyl)-4-propyl- 1, 3-dioxolan-2-yl] methyl]-1h-1,2,4-trizole) was applied at 0.030624 gallons per acre at GS 9 with a second application at GS 10 before heading to control Glume-Blotch severity. In 1999 and 2000, a single application of Quadris (azoxystrobin: methyl (E)-2(2-{6-(2-cyanophenoxyl)pyrimidin-4-yloxylphenyl}-3-methoxyacrylate)) was applied at 0.0616704 gallons per acre at GS 9 to control disease severity. Propiconazole and Quadris are both foliar fungicides used to control Glume-Blotch severity (Bailey, 2002). No chemicals were applied to control Take-All because no effective chemical control exists to limit Take-All severity (Colbach, 1997). Disease ratings were recorded each year at GS 10.1 when the sheath of the last leaf was completely grown out. Disease ratings were recorded on a scale of zero to ten, with ten being the most severe disease rating and zero being no disease present. Plots were harvested mid-June.

*Empirical Model*

A Just-Pope model was specified to evaluate the risk effects of two N sources, and two diseases at five N fertilization dates. The mean yield production function $f(X_t,\beta)$ for each N source was estimated as a quadratic function of the management variable time;

$$(2) \qquad Y_t = \beta_0+\beta_1 time_t+\beta_2 time_t^2+e_t,$$

where Y was wheat yield (bu/acre), time was the day of the year N was applied; t was a subscript indicating year; $\beta_0$, $\beta_1$ and $\beta_2$ were parameters to be estimated; and e was a random error term with a mean of zero. Time was hypothesized to exhibit diminishing marginal productivity ($\beta_1 > 0$, $\beta_2 < 0$).

The variance of yield function $h(Z_t,\alpha)\varepsilon_t$ was estimated using the residuals obtained from the mean yield production function. Because Glume-Blotch and Take-All severity affect wheat yield differently (Boquet, 1987; Colbach, 1997), variance of yield was specified as a function of time, Glume-Blotch rating, Take-All rating, two dummy variable for disease presence, an interaction between time and Glume-Blotch rating, and an interaction between time and Take-All rating. The Just-Pope approach enables direct statistical testing of hypotheses about how time, Glume-Blotch severity, and Take-All severity interact to influence risk in wheat production for alternative N sources. The variance of yield function for each N source was specified as:

$$(3)\ln\hat{e}_t^2 = \alpha_0+\alpha_1 time_t+ \alpha_2 G_t+\alpha_3 DG_t+\alpha_4 timeG_t+\alpha_5 TA_t+\alpha_6 DTA_t+\alpha_7 timeTA_t+u_t,$$

where $\ln\hat{e}_t^2$ was the natural log of the squared residuals from equation 2; time was the day of the year N was applied; G was Glume-Blotch rating, with 10 being the most severe disease rating and zero being when no disease was present; DG was an dummy variable equal to one when the disease was present and zero otherwise; timeG was an interaction term between N timing and Glume-Blotch rating; TA was the Take-All rating, with 10 being the most severe disease rating and zero being when no disease was present; DTA was an dummy variable equal to one when the disease was present and zero otherwise; timeTA was an interaction term between N timing and Take-All rating; $\alpha_i$ ($i = 0,1,\ldots, 7$) were parameters to be estimated; and u was a random error term with a mean of zero.

Efficiency gains in parameter estimates are possible with weighted least squares (WLS) when multiplicative heteroscedasticity is found. Multiplicative heteroscedasticity in the mean yield equations (2) was tested using the model F-statistic from the individual N source variance equations (Judge et al.,1982). If the F-statistic was significant, the null hypothesis of homoscedasticity was rejected and multiplicative heteroscedasticity was assumed. Predicted values from equation 3 were used as weights for producing WLS estimates for the mean yield equation (equation 2) for each N source.

Net returns were calculated using an average wheat price of $3.43/bu for 1991-2000 (Tennessee Department of Agricultural, 2001). Wheat prices were inflated to 2002 dollars by the Gross Domestic Product Implicit Price Deflator (U.S. Department of Commerce: Bureau of Economic Analysis, 2002) before averaging. N fertilizer prices were obtained from the Tennessee Farmers Cooperative. Tennessee average retail prices paid by farmers for 2002 were: AN = \$0.26/lb; Urea = \$0.21/lb; and UAN = \$0.23/lb (Personal Communication, John Duke, Tennessee Farmers Cooperative, June 17, 2002). All prices were for pure N. Other production costs were assumed not to change among alternatives.

The estimated mean yield response function and the variance function for each N source were used to predict certainty equivalent optimizing N timing, yield, cost, and net return above N cost. Certainty equivalent of per-acre profit was approximated as (Robison and Barry, 1987):

$$(4) \qquad CE = E(NR) - \lambda/2\ Var(NR),$$

where E(NR) was expected net return, $\lambda$ was the value of the Pratt-Arrow absolute risk aversion coefficient, and Var(NR) was the variance of net return. E(NR) was calculated using the following formula:

$$(5) \qquad E(NR) = (Y*WP)-(N*NP),$$

where Y was the wheat yield (bu/acre); WP was the average wheat price per bushel from 1991-2000; N was the N rate (lb/acre); and NP was the price per pound of pure N. Var(NR) was calculated using the following formula (Bohrnstedt and Goldberger, 1969):

$$(6) \qquad Var(NR) = (Y^2)*WP_{var}+WP^2(Y_{std})+WP_{var}(Y_{std}),$$

where Y was wheat yield (bu/acre); WP was the average wheat price per bushel from 1991-2000; $WP_{var}$ was the wheat price variance from 1991-2000 of \$0.61/bu; $Y_{std}$ was the standard deviation of wheat yield obtained from equation 3.

The certainty equivalent maximizing N fertilization date for each N source was found by solving:

$$(7) \quad \max CE = E(NR) - \lambda/2 \, Var(NR),$$

$$\text{s.t.} \quad 46 \leq \text{time} \leq 105 \text{ days.}$$

Equation 7 was solved for risk neutrality ($\lambda = 0$) and two levels of risk aversion, ($\lambda = 0.01$ and $\lambda = 0.02$), consistent with the range of risk aversion evaluated by Lambert, (1990) and Larson, (2001).

Farmers' willingness to pay was the maximum dollar amount they would pay for the knowledge that one N source was more profitable than another N source for each risk aversion level and be just as well off. Dollar amounts lower then the willingness to pay would be considered profit by farmers and be an incentive to switch N sources. Willingness to pay was calculated by determining the difference between the certainty equivalents of the N sources for risk neutrality and the two levels of risk aversion.

## Results and Discussion

*Mean Yields*

The mean yield response functions were estimated with WLS (Table 1) after the F-statistic for the variance of yield equations indicated multiplcative heteroscedasticity. The WLS coefficients for time and time$^2$ had the hypothesized signs (Figure 2). The low $R^2$ coefficients suggest that a considerable amount of variation in wheat yield was not explained by the management variable time. Error sums of squares from the OLS regressions for the mean yield functions (equation 2) indicate that AN and UAN did not produce significantly different variation in wheat yields (F = 0.10, df 72/72).

*Variance of Yields*

The variance of yield equations are presented in Table 2 and joint F-tests for the time and disease coefficients are presented in Table 3. The time and Glume-Blotch coefficients were not significantly different from zero for both N sources. However, the Take-All ratings coefficient (TA) and the dummy variable coefficient (DTA) were significant at the 10-percent level for AN; TA positively affected risk and DTA negatively affected risk. The joint F-tests (Table 3) indicated that Take-All significantly reduced risk when AN was applied (Table 4) from no disease present to mean Take-All rating with other variables held constant at their means. Take-All reduces risk possibly because the ammonium form of AN may have reduced Take-All severity in the higher yielding area of the field compared to the lower yielding area of the field where N had little benefit on yield, thus equalizing yields across the field. No other coefficients were significantly different from zero. Pair-wise F-tests indicated that time, Glume-Blotch and Take-All do not affect risk differently among N sources (Table 5).

*Risk-Return Trade-offs*

Optimal fertilization dates, wheat yields, wheat yield standard deviations, net return means, and certainty equivalents for each N source under the assumption of risk neutrality ($\lambda = 0$) and two levels of risk aversion ($\lambda = 0.01$ and $\lambda = 0.02$) for mean disease ratings are presented in Table 6. Optimal fertilization dates, wheat yields, wheat yield standard deviations and net return means were not affected by the different risk aversion levels. Optimal fertilization dates were March 8 and March 9 for AN and UAN. The optimal wheat yields were 67 and 62 bu/acre. Optimal net returns were $206.32 and $190.54 for AN and UAN. Certainty equivalents were $206.32 ($192.07) (($177.82)) and $190.54 ($178.33) (($166.12)) for risk neutrality and the two levels of risk aversion for AN and UAN. Farmers willingness to pay was $15.78 ($13.74) (($11.70)) per acre for risk neutrality and the two levels of risk aversion for AN vs. UAN.

Certainty equivalents can be used to rank N sources for individuals with different levels of risk aversion. AN had the highest net return and the highest certainty equivalents at all levels of risk aversion evaluated. AN was the utility maximizing N source for all levels of risk aversion. Results indicate that farmers will maximize utility and net returns if they apply AN on March 8, regardless of their risk aversion level.

## Summary

This study evaluated risk efficiency of alternative N sources and five different fertilizations dates in wheat production in the presence of two diseases (Glume-Blotch and Take-All). A Just-Pope econometric model was developed to analyze the risk effects of alternative N sources and to evaluate risk and return tradeoffs among these N sources.

The results indicated that time had no affect on risk ant that AN was the optimal N source. However, the presence of Take-All reduced risk when AN was applied. The risk-return trade-offs suggested that time had no effect on utility maximizing N source at the different risk aversion levels. At mean values of the disease variables, AN was the utility maximizing N source regardless of the farmers risk preferences. This information could be used to recommend that farmers apply AN on March 8, regardless of a farmer's risk aversion level.

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**Table 1.** Estimated Weighted Least Squares Wheat Yield Response Functions for Alternative Nitrogen Sources, Nitrogen Fertilization Date Equations.

| | Nitrogen sources | |
|---|---|---|
| Variables[a] | AN | UAN |
| Intercept | 5.11 | -12.65 |
| | (39.62)[b] | (36.36) |
| time | 1.85* | 2.17* |
| | (1.18) | (1.015) |
| time$^2$ | -0.014* | -0.016* |
| | (0.0072) | (0.0067) |
| Error Sums of Squares[c] | 26,982 | 25,424 |
| $R^2$ | 0.10 | 0.12 |
| n | 75 | 75 |

[a] Wheat yield (bu/acre) is the dependent variable and time is the application date of N.
[b] Numbers in parenthesis are standard errors.
* significantly different from zero at the 10-percent level.
[c] From OLS estimates.

**Table 2.** Estimated Ordinary Least Squares Wheat Variance Functions for Alternative Nitrogen Sources, Nitrogen Fertilization Date Equations.

| Variables[a] | Nitrogen sources | |
|---|---|---|
| | AN | UAN |
| Intercept | 4.83***<br>(1.20)[b] | 5.75***<br>(0.98) |
| time | 0.015<br>(0.015) | 0.0025<br>(0.013) |
| G | -0.020<br>(0.45) | -0.082<br>(0.37) |
| DG | -3.30<br>(3.069) | -2.64<br>(1.79) |
| timeG | -0.000058<br>(0.0030) | -0.00049<br>(0.0028) |
| TA | 0.804*<br>(0.46) | 0.023<br>(0.38) |
| DTA | -3.38***<br>(0.0048) | -1.029<br>(0.81) |
| timeTA | -0.0028<br>(0.0048) | -0.00046<br>(0.0036) |
| F-statistic | 10.10*** | 13.54*** |
| $R^2$ | 0.51 | 0.59 |
| n | 75 | 75 |

[a] Wheat yield (bu/acre) is the dependent variable; time is the application date of N; G is Glume-Blotch rating, with 10 being the most severe disease rating and zero being when no disease was present; DG is an dummy variable that is one when disease is present and zero otherwise; timeG is an interaction term between N timing and Glume-Blotch rating; TA is the Take-All rating, with 10 being the most severe disease rating and zero being when no disease was present; DTA is an dummy variable that is one when the disease is present and zero otherwise; and timeTA is an interaction term between N timing and Take-All rating.

[b] Numbers in parenthesis are standard errors.

*** and * significantly different from zero at the 1 or 10-percent level, respectively.

**Table 3.** Joint F-tests for the Nitrogen Fertilization Date, Glume-Blotch, and Take-All Coefficients within the Variance Equations for Each Nitrogen Source, Nitrogen Fertilization Date Equations.

| Comparisons | F-statistic |
|---|---|
| **Time**[a] | |
| AN | 0.51 |
| UAN | 0.02 |
| | |
| **Glume-Blotch**[b] | |
| AN | 0.04 |
| UAN | 2.62 |
| | |
| **Take-All**[c] | |
| AN | 3.24* |
| UAN | 1.21 |

[a] The F-statistic test the null hypothesis that the coefficients for N, NG, and NTA are jointly equal to zero for a given N source.

[b] The F-statistic test the null hypothesis that the coefficients for G, DG, and NG are jointly equal to zero for a given N source.

[c] The F-statistic test the null hypothesis that the coefficients for TA, DTA, and NTA are jointly equal to zero for a given N source.

* significantly different from zero at the 10-percent level.

**Table 4.** Estimated Effects of Take-All on Risk for UAN.

| Variables | No disease[a] | Mean disease[b] |
|---|---|---|
| time | 75 | 75 |
| G | 2.41 | 2.41 |
| DG | 0.33 | 0.33 |
| timeG | 180.75 | 180.75 |
| TA | 0 | 4.58 |
| DTA | 0 | 1 |
| timeTA | 0 | 343.5 |
| | | |
| Wheat Yield Std. Dev. | 11.09 | 7.95 |

[a] Variables other than TA, DTA, and timeTA are held constant at their three-year means.

[b] Take-All variables TA, DTA, and timeTA are at their 2000 means, other variables are held constant at their three-year means.

**Table 5**. Pair-Wise F-tests for the Nitrogen Fertilization Date, Glume-Blotch and Take-All Coefficients between Nitrogen Sources, Nitrogen Fertilization Date Equations.

| Comparisons | F-statistic |
|---|---|
| **Time**[a] | |
| AN-UAN | 0.15 |
| **Glume-Blotch**[b] | |
| AN-UAN | 0.26 |
| **Take-All**[c] | |
| AN-UAN | 0.37 |
| **Equation**[d] | |
| AN-UAN | 0.06 |

[a] The F-statistic tests the null hypothesis that the coefficients for time, timeG, and timeTA are equal between N sources.

[b] The F-statistic tests the null hypothesis that the coefficients for G, DG, and timeG are equal between N sources.

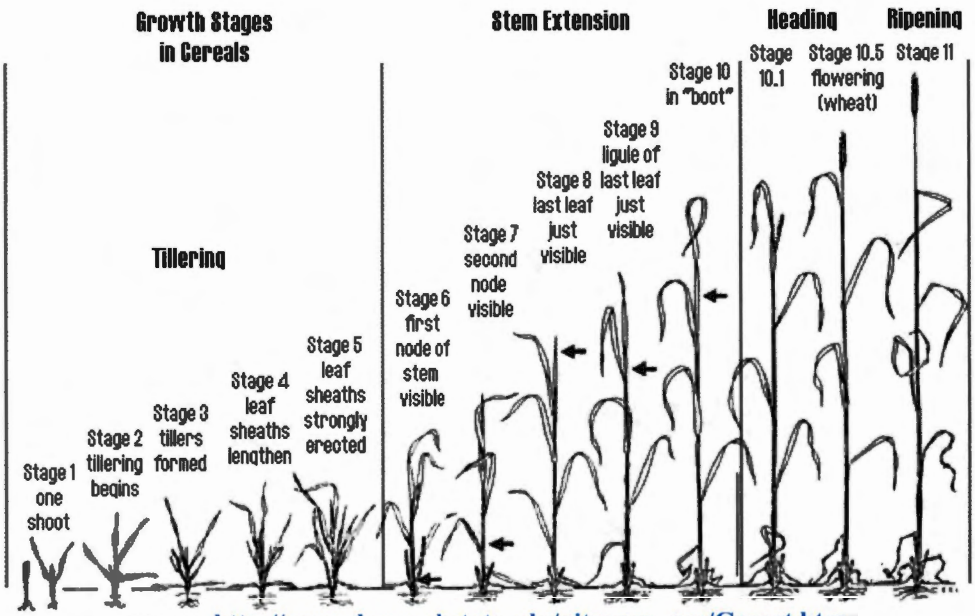
[c] The F-statistic tests the null hypothesis that the coefficients for TA, DTA, and timeTA are equal between N sources.

[d] The F-statistic tests the null hypothesis that the yield variance equations are equal between N sources.

**Table 6.** Risk and Return Comparisons for Nitrogen Sources at Three Levels of Risk Aversion, Nitrogen Fertilization Date Equations.

| **Nitrogen Sources**[a] | **Coefficient of Absolute Risk Aversion** | | |
|---|---|---|---|
| | $\lambda$=0.00 | $\lambda$=0.01 | $\lambda$=0.02 |
| ***Ammonium Nitrate (AN)*** | | | |
| Fertilization date | March 8 | March 8 | March 8 |
| Wheat Yield (bu/acre) | 67 | 67 | 67 |
| Yield Std. Dev. (bu/acre) | 9 | 9 | 9 |
| Net Return Mean ($/acre) | $206.32 | $206.32 | $206.32 |
| Certainty Equivalent | $206.32 | $192.07 | $177.82 |
| ***Urea-Ammonium Nitrate (UAN)*** | | | |
| Fertilization date | March 9 | March 9 | March 9 |
| Wheat Yield (bu/acre) | 62 | 62 | 62 |
| Yield Std. Dev. (bu/acre) | 11 | 11 | 11 |
| Net Return Mean ($/acre) | $190.54 | $190.54 | $190.54 |
| Certainty Equivalent | $190.54 | $178.33 | $166.12 |

[a] Disease variables are held constant at their three-year means.




source: http://www.dasnr.okstate.edu/nitrogen_use/Gscart.htm

| Growth Stage | | Description |
|---|---|---|
| *Tillering*: | 1 | One shoot (number of leaves can be added) = "braiding" |
| | 2 | Beginning of tillering |
| | 3 | Tillers formed, leaves often twisted spirally. In some varieties of winter wheat, plants may be "creeping" or prostrate |
| | 4 | Beginning of the erection of the pseudo-stem, leaf sheaths beginning to lengthen |
| | 5 | Pseudo-stem (formed by sheaths of leaves) strongly erected stem-extension |
| | 6 | First node of stem visible at base of shoot |
| | 7 | Second node of stem formed, next-to-last leaf just visible |
| | 8 | Last leaf visible, but still rolled up, ear beginning to swell |
| | 9 | Ligule of last leaf just visible |
| | 10 | Sheath of last leaf completely grown out, ear swollen but not yet visible |
| *Heading:* | 10.1 | First ears just visible (awns just showing in barley, ear escaping through split of sheath in wheat or oats) |
| | 10.2 | Quarter of heading process completed |
| | 10.3 | Half of heading process completed |
| | 10.4 | Three-quarters of heading process completed |
| | 10.5 | All ears out of sheath |
| *Flowering:* | 10.5.1 | Beginning of flowering (wheat) |
| | 10.5.2 | Flowering complete to top of ear |
| | 10.5.3 | Flowering over at base of ear |
| | 10.5.4 | Flowering over, kernel watery ripe |
| *Ripening:* | 11.1 | Milky ripe |
| | 11.2 | Mealy ripe, contents of kernel soft but dry |
| | 11.3 | Kernel hard (difficult to divide by thumbnail) |
| | 11.4 | Ripe for cutting. Straw dead |

**Figure 1.** Physiological Growth Stages in Winter Wheat (Large, 1954).

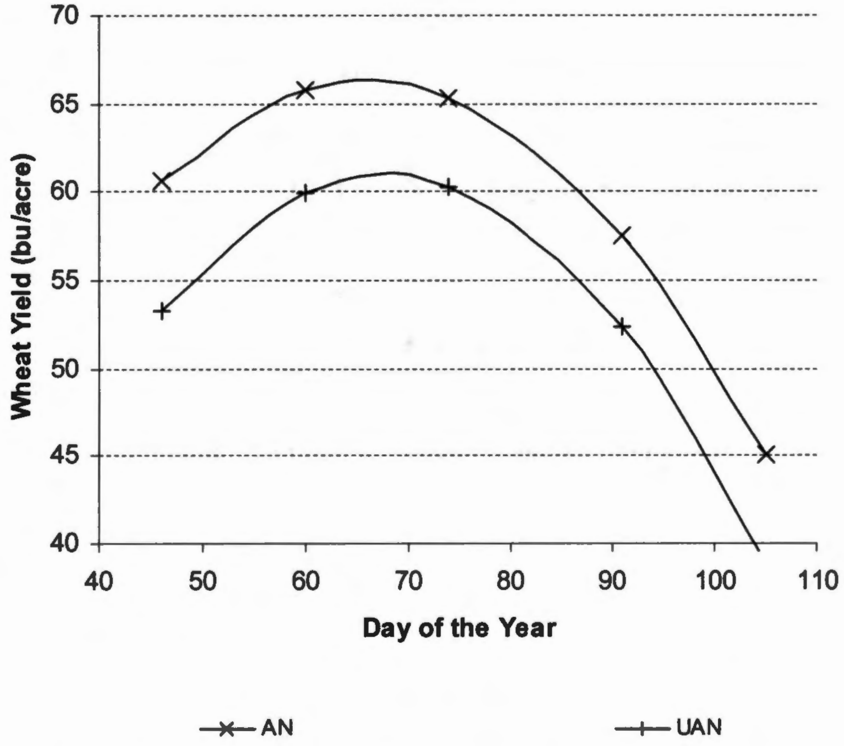



**Figure 2.** Nitrogen Fertilization Date Weight Least Squares Yield Response Functions.

## Summary

This study evaluated risk efficiency in wheat production for alternative N sources, six application rates, and five fertilization dates in the presence of two diseases (Glume-Blotch and Take-All). A Just-Pope econometric model was developed to analyze the risk effects of alternative N sources and to evaluate risk and return trade-offs among these N sources.

The results indicated that N had no affect on risk and that AN was the optimal N source. The presence and severity of disease had an influence on risk. In the presence of Glume-Blotch and Take-All, UAN significantly reduced risk at mean N rates and disease ratings, but risk was not reduced enough for UAN to replace AN as the utility maximizing N source. The risk-return trade-offs suggest that N had no effect on utility maximizing N source at different risk aversion levels.

The results indicated that time had no effect on risk and that AN was the optimal N source. The presence and severity of Take-All reduced risk when AN was applied. The risk-return trade-offs suggested that time had no effect on utility maximizing N source at the different risk aversion levels. At mean values of the disease variables, AN was the utility maximizing N source regardless of the farmer's risk preferences.

For both N rate and N fertilization date, AN was the utility maximizing N source. This information could be used to recommend that farmers apply AN at a rate around 90 lb N/acre on March 8 regardless of the wheat producer's level of risk aversion.

## Vita

Jeremy Tate Walters was born in Maryville, Tennessee, on January 20, 1978 to Gary and Diana Walters. He has one brother, Adam Walters. Jeremy is the husband of Alice Michelle Walters and the father of Hunter Tate Walters. He attended schools in the public school system of Blount County, Tennessee, where he graduated from Heritage High School in May of 1996.

In August of 1996, he entered Hiwassee College in Madisonville, Tennessee. In August of 1998, he transferred to The University of Tennessee, Knoxville. In December 2000, he received a Bachelor of Science degree with a major in Agricultural Economics. In January 2001, he entered the Master's program in The Agricultural Economics and Rural Sociology Department at The University of Tennessee, Knoxville. Jeremy received his Master of Science degree in Agricultural Economics in December 2002.